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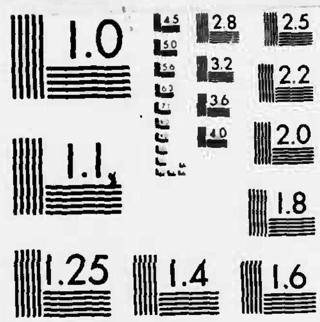

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Monterey, California

THESIS

EDUCATIONAL AIDS IN AIRCRAFT
COMBAT SURVIVABILITY

by

Patrick G. Cox

December 1983

Thesis Advisor: R. E. Ball

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This thesis presents four additions prepared for the textbook "The Fundamentals of Aircraft Combat Survivability Analysis and Design" by Professor Robert E. Ball. A set of homework problems with solutions was developed for the textbook to provide the user with a means of measuring student progress. An index, a lexicon of terminology, and a formulary were also developed to enhance the usability of the textbook.

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Educational Aids in Aircraft Combat Survivability

by

Patrick G. Cox
Lieutenant Commander, United States Navy
B.S., Kansas State University, 1969

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December, 1983

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ABSTRACT

This thesis presents four additions prepared for the textbook "*The Fundamentals of Aircraft Combat Survivability Analysis and Design*" by Professor Robert E. Ball. A set of homework problems with solutions was developed for the textbook to provide the user with a means of measuring student progress. An index, a lexicon of terminology, and a formulary were also developed to enhance the useability of the textbook.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

The textbook [Ref. 1] by Professor Robert E. Ball, Naval Postgraduate School, will, when published, be the first textbook in the aircraft combat survivability discipline. As such, it will be used by persons in many and diverse fields as their principal source document for concepts, terminology, computational techniques, and modeling methodology in survivability. Table I presents the table of contents of the book. It will be used by aeronautical engineers to improve the survivability of aircraft in the various design stages. Tacticians will use its concepts to evaluate strategies to reduce the susceptibility of operating aircraft. Computer specialists and mathematicians will use it to gain a better insight into the processes and scenarios they are attempting to model.

Four additions to the textbook are presented in this thesis. Homework problems and detailed solutions for each chapter in the textbook are given in Appendix A. A Lexicon of terms is presented in Appendix B, an Index of terms is given in Appendix C, and the important formulae and their variables are presented in Appendix D for one easy reference point.

The homework problems were developed based upon a number of criteria. Certain homework problems were developed specifically to support the stated objectives of the book. These range from simple definitions to the development of complex logical statements. In several cases, multiple questions are used to explore different aspects of a single objective. Mathematical problems were developed for chapters IV, V, VI, and VII, both to exercise the specific

TABLE I

Textbook Table of Contents

mathematical techniques presented and to give the student representative examples of aircraft survivability assessment under realistic conditions. Multiple techniques, when available, are used to solve the same problem. This is done both to demonstrate the equivalence of the techniques and to allow the student the opportunity to determine which technique best suits his/her needs. The important concepts of the discipline are investigated in some questions, both by asking specifically for enumeration of various techniques and by giving the student the opportunity to demonstrate these concepts to himself through calculation. In all instances, an attempt was made to provide questions which ranged from simple to quite challenging in order to provide suitable questions for students from all backgrounds.

A Lexicon of terms was developed to provide definitions of those terms which might not be familiar to the student. It is recognized that, although the text is primarily concerned with aviation, not all those who use it will be aviators or aeronautical engineers. Through the use of a Lexicon it is possible to streamline the text of the book by dispensing with lengthy definitions without sacrificing comprehension of the material.

A Formulary was developed to assemble in one readily accessable location those important formulae and equations most commonly used in the discipline. The variables used in these equations are assembled in alphabetical order in order to facilitate the use of the formulary. No sample problems are included because these were provided by the author in the body of the text.

An Index was developed to allow rapid access to specific information not identified by the table of contents. Since the book has not yet been typeset and page numbers are not available, the important location of each item in the index has been specified by chapter and paragraph number. The six level paragraph organization of this text made this approach quite acceptable.

The text in its final stages was proof read by this student several times to assist in providing the best possible product to the potential user, and a system of index cards was developed to prevent errors from creeping into the various formulae in the book.

II. SUMMARY AND CONCLUSIONS

A properly written text should contain more than the factual information of the discipline. It should provide a means for the student to evaluate his own progress, and it should provide a means for the rapid access to the critical concepts and relationships used in the discipline. This thesis will provide these necessary additions to [Ref. 1].

APPENDIX A

DUE TO INABILITY OF THIS DEVICE TO PRINT SUBSCRIPTS

THE FOLLOWING NOTATION WILL BE USED

DESCRIPTION	FOR THE ITH COMPONENT	FOR THE AIRCRAFT
Probability of hit	P<hi>	P<H>
Probability of kill given a hit	P<k/hi>	P<K/H>
Probability of kill of the ith component given a hit	P<k/Hi>	
Probability of kill	P<ki>	P<K>
probability of survival	P<si>	P<S>
Vulnerable area	A<vi>	A<V>
Presented area	A<pi>	A<P>
probability of detection given one scan by a radar		P<ds>

Cumulative probability of detection	P<CD>
Cumulative probability of detection given S scans by a radar	P<cd>
Probability of kill given a one-on-one encounter	P<K/E>
Probability of kill given a single shot	P<KSS>
Probability of kill given multiple encounters	P<K/M>
Probability of kill given a warhead detonation	P<K/D>
Probability a fuzed warhead is detonated	P<f>
Probability that a propagator will be launched/fired at the aircraft	P<L>

Probability the aircraft survives a single shot encounter	P<S/E>
Probability an aircraft survives a sortie	P<S/S>

HOMEWORK PROBLEMS IN SURVIVABILITY

CHAPTER I

1. Define the following terms:

   A. Aircraft combat survivability.

   B. Aircraft susceptibility.

   C. Aircraft vulnerability.

2. List the three general categories of susceptibility.

3. If susceptibility = 0.1 and vulnerability = 0.08, what is the probability of kill and the probability of survival?

4. Describe the goal of the aircraft combat survivability discipline.

5. List the six vulnerability reduction concepts. List specific examples of each of the vulnerability reduction concepts you listed. If you are directly associated with a military aircraft, attempt to list examples of some of the concepts used on your aircraft.

6. List the six susceptibility reduction concepts. List examples of the susceptibility reduction concepts you listed. If you are directly associated with a military aircraft, attempt to list examples of some of the concepts used on your aircraft.

7. What agency is responsible for coordinating the individual Service programs to increase the combat survivability of aeronautical systems in a non-nuclear environment?

8. Briefly describe the purpose and content of NASP.

9. Briefly describe the purpose and content of MIL-STD-2069(AS).

10. What is the function of a foreward-area controller (FAC)?

11. What is the mission attainment measure (MAM) a measure of?

12. What does the survival rate (S) measure?

13. What is the first step in the survivability enhancement feature selection methodology?

14. What publication exists to standardize terminology in the survivability discipline?

15. At what point in the life cycle of a military aircraft does survivability become an important consideration?

16. What effect on vulnerability did the transition to turboshaft engines in helicopters have? What other effects might have to be considered in this transition?

17. What is the purpose of the various foams inserted into fuel tanks?

ANSWERS (CHAPTER I)

1. A. Survivability: The capability of an aircraft to avoid and/or withstand a man-made hostile environment.

B. Susceptibility: The inability of an aircraft to avoid being damaged by the hostile environment.

C. Vulnerability: The inability of an aircraft to withstand the damage caused by the hostile environment.

2. The three general categories of susceptibility are:

   A. Threat activity

   B. Aircraft detection, identification, and tracking.

   C. Missile launch or gun firing, propagator flyout guidance, and warhead impact or detonation.

3. Probability of kill = 0.008

   Probability of survival = 0.992

4. The goal of the ACS discipline is the early identification and successful incorporation of those specific survivability enhancement features that increase the effectiveness of the aircraft as a weapon system.

5. The vulnerability reduction concepts are:

A. Component redundancy

B. Component location

C. Passive damage suppression

D. Active damage suppression

E. Component shielding

F. Component elimination

Examples of the vulnerability reduction concepts are:

A. Component redundancy

-Multiple engines

-Dual, isolated flight control systems

B. Component location

-Widely separated redundant components

C. Passive damage suppression

-Ballistic tolerance

-Fail-safe response

D. Active damage suppression

-Fire extinguishing systems for engine compartments

E. Component shielding

-Parasitic armor

-Integral armor

-By other components

F. Component elimination

-Fly-by-wire vice pushrods

-Replace fuel boost pumps with suction feed system

6. The susceptibility reduction concepts are:

A. Threat warning

B. Electronic jammers and deceivers

C. Signature reduction

D. Expendables

E. Threat suppression

F. Tactics

Examples of the susceptibility reduction concepts are:

A. Threat Warning

-Missile launch warning equipment

B. Electronic jammers and deceivers

-IR jammers

-Radar warning receivers

C. Signature reduction

-Non-reflective paints and coatings

-Secure non-essential emitters prior to entering the battle area

D. Expendables

-Flares

-Chaff

-Decoy missiles

E. Threat suppression

-Iron Hand

-Wild Weasel

F. Tactics

-NOE flight

7. The agency responsible for interservice coordination is the Joint Technical Coordinating Group on Aircraft Survivability. (JTCG/AS).

8. Navair Instruction 3920.1, CH-1, "Establishment of Naval Air Survivability Program (NASP)", establishes aircraft survivability as a design discipline in the Navy. It provides the proceedures, responsibilities and relationships for the NASP within the Naval Air Systems Command.

9. Military standard: "Survivability, Aircraft: Establishment and Conduct of Programs for."

It provides a standardized systems approach to improve the survivability of military aircraft.

10. The purpose of the forward air controller is to assist the combat aircrew in rapid location of its target.

11. The Mission Attainment Measure is a measure of the ability of the aircraft to accomplish its objective, without consideration of the threat effects.

12. The survival rate is the ratio of the number of aircraft that return to the number of aircraft launched.

13. The first step in the survival enhancement feature selection methodology is the mission-threat analysis.

14. Military Standard MIL-STD-2089, "Aircraft Nonnuclear Survivability Terms" standardizes terminology for the survivability discipline.

15. A. Often, the first time it is shot at.

B. Ideally, in the early design phase, to eliminate the necessity of a costly retrofit program following production.

16. Turboshaft engines increased the vulnerability of helicopters, because both the turbine engines and their high speed transmissions were more fragile than the systems they replaced. Turboshaft engines are lighter, which could result in a lower gross weight. However, they burn more fuel, which would require larger fuel tanks. On the other hand, they burn turbine fuel, which is less easily ignited than avgas, which could make the aircraft less vulnerable.

17. Foams are used in fuel tanks to suppress fires and explosions.

CHAPTER II

1. List the five major aircraft systems. What three flight essential functions do these systems provide?

2. List the five other systems found on most aircraft.

3. What are the major differences between rotary wing aircraft and fixed wing aircraft?

4. What are the main structural members in the wing and in the fuselage?

5. What is a keel?

6. Describe semimonocoque construction.

7. List functions that the fuel must sometimes perform in addition to its obvious function.

8. Why are the fuel and the armament typically located close to the center of mass of the airplane?

9. Carrier-based aircraft have several structural penalties that other aircraft do not have. List those you can think of.

10. list the types of turbine engines and the speed ranges you would normally expect them to be used in.

11. What is the function of the accessory drive on an engine?

12. What is dynamic stability?

13. What is static stability?

14. List the general types of aircraft in decreaseing order of stability required.

15. Why are fighter aircraft generally designed to be less stable than other types of aircraft?

16. Why are transport aircraft generally designed to be very stable?

17. Can an aircraft that is statically stable be dynamically unstable? Explain your answer.

18. Define relaxed static stability.

19. Why is artificial feel added to the flight control systems of aircraft with power boosted or power operated control surfaces?

20. List the various control surfaces used on aircraft.

21. What is a trim tab and why is it used?

22. Define fly-by-wire.

23. What is the purpose of the automatic flight control system?

24. What is a "wet wing"? Why are wet wings sometimes used?

25. Why are wet tanks seldom used in the fuselage of aircraft?

26. Why is the ullage of aircraft fuel tanks usually pressurized?

27. What is the sump or feed fuel tank?

28. The oxygen subsystem is part of what system?

29. What are the major control surfaces of a helicopter?

ANSWERS (CHAPTER II)

1. The major aircraft systems are:

   A. Structural

   B. Propulsion

   C. Flight Control

   D. Fuel

   E. Crew

Lift, thrust, and control are the three essential functions these systems provide.

2. The five other systems most aircraft have are:

   A. Avionics

   B. Armament

   C. Environmental control

   D. Electrical

   E. Launch and reccvery

3. Helicopters are very power limited and hence must be very lightly constructed. Thrust, lift, and control are all provided by the rotor system in helicopters, leading to

mechanical complexity in the controls of the rotor system. Fuel tanks in helicopters are typically located in the bottom of the fuselage, necessitating pumping systems to deliver fuel to the engines at all times.

4. The main structural members are:

   Wing: Spars (spanwise) and ribs (chordwise).

   Fuselage: Longerons (lengthwise) and frames or bulkheads (laterally).

5. A keel is a major fuselage beam running lengthwise.

6. Semimonocoque construction is a construction technique which derives significant strength from the skin of the aircraft.

7. A. Fuel is occassionally used as a coolant, such as of the lubricating oil.

   B. It is sometimes used as a hydraulic fluid to operate variable area exhaust nozzles and/or variable inlet guide vanes.

   C. In addition, fuel is quite often the working fluid in the fuel control and may provide lubrication to the mechanical systems of the fuel control.

8. To prevent large shifts in center of gravity (cg) during flight as fuel and especially ordnance are used.

9. Carrier based aircraft generally require:

Folding wings or rotor systems.

More heavily constructed landing gearand supporting structure.

Provisions for catapault launchand arrested landings (fixed wing).

10. The general types of turbine engines and their typical usages are:

A. Turboshaft	Helicopter
B. Turboprop	Low to mid subsonic
C. Turbofan	Subsonic, with supersonic dash capability when an afterburner is used
D. Turbojet	High subsonic and supersonic

11. The accessory drive provides power for fuel pumps, electric generators, hydraulic pumps, fuel control, and variable area exhaust nozzles and inlet guide vanes.

12. Dynamic stability is a tendency for induced oscillations to damp out without input to the controls.

13. If an aircraft has the initial tendency to move in the direction of its original attitude after displacement, it is said to have static stability.

14. The general stability groupings of aircraft are:

A. Transport/cargo aircraft (most stable)

B. Attack/bomber aircraft

C. Fighter/interceptor aircraft (least stable)

15. The more stable an aircraft is, the less agile it is; it has less ability to maneuver rapidly. Consequently, fighter aircraft are not designed to be highly stable.

16. As stability is increased, pilot workload goes down, reducing fatigue on long flights.

17. Yes, if it overshoots its original attitude following a disturbance by an amount greater than its initial displacement.

18. Relaxed static stability is a design technique which utilizes a flight control computer to provide artificial stability to an aircraft which may be so naturally unstable as to be impossible to control without the computer.

19. Artificial feel is used to provide tactile warning to the pilot when structural limits are being approached as the controls are deflected.

20. The various control surfaces used by aircraft are:

A. Elevators

B. Elevons

C. Spoilers (flaperons)

D. Ailerons

E. Speed brakes

F. Rudders

G. Canards

H. Stabilators

I. Leading and trailing edge flaps

J. Leading edge slats

K. Main rotor blades

L. Tail rotor blades

21. A trim tab is a small tab located at the trailing edge of a control surface. It is used to reduce the magnitude of the control forces required to maintain a selected aircraft attitude.

22. Fly-by-wire is the use of electrical signals to convey control inputs to servoactuators, eliminating major portions of the mechanical linkage.

23. The automatic flight control system (AFCS):

A. Augments the aircraft's natural stability.

B. Provides automatic commands to hold a preselected altitude, attitude, and heading.

24. A wet wing is a fuel tank constructed integrally with the wing skin. A wet tank maximizes the amount of fuel which can be stored in a space, since no fuel bladder or separate tank is required. In addition, a wet tank is often the only way a thin wing can carry fuel due to the presence of internal structure.

25. Wet tanks are not used in the fuselage because of leakage problems.

26. The ullage of fuel tanks is usually pressureized:

A. To assist in fuel transfer.

B. To prevent the fuel from boiling at high altitude.

27. The sump tank is the tank which feeds directly to the engine.

28. The oxygen subsystem is part of the environmental control system.

29. The principal control surfaces of a helicopter are its main and tail rotor blades.

CHAPTER III

1. What are the four categories of terminal threat platforms?

2. List the three categories of threat propagators and give an example of each.

3. What is the largest gun considered a small arm?

4. What is the smallest category of gun that is considered AAA?

5. What is the counterpart of the conventional warhead for directed energy weapons?

6. What are the two basic categories of conventional warheads?

7. What is another name for a non-fuzed warhead?

8. What are the four major types of high explosive warheads?

9. What damage processes are associated with penetrators?

10. Why is depleted uranium sometimes used for penetrator cores?

11. What would the principal damage mechanism of a charged nuclear particle weapon be when directed against an aircraft?

12. What is the general sequence of events of threat operations?

13. What is the definition of the maximum target detection range?

14. What is the definition of maximum effective range of a weapon?

15. What is lead angle prediction error?

16. What are the most common guidance systems used by todays missiles?

17. What are the three major types of homing systems used by todays missiles?

18. What are the most common control laws used by missiles for navigation?

19. What are the three phases of guidance?

20. which phase of guidance requires the highest accuracy and fastest reaction time?

21. Describe the major parts of a typical explosive warhead.

22. What basic types of fuzing may be used on projectile and missile warheads?

23. What are the essential elements of a mission-threat analysis?

ANSWERS (CHAPTER III)

1. The four categories of terminal threat platforms are:

   A. Guns

   B. Missiles

   C. Airborne interceptors

   D. Directed energy devices

2. The three categories of threat propagators are:

   A. Projectiles (7.62mm)

   B. Fuzed missiles (SA-6)

   C. Radiation (high energy laser)

3. The largest gun considered a small arm is 14.5mm.

4. The smallest gun considered AAA is 20mm.

5. The counterpart of the conventional warhead for directed energy weapons is the delivered energy distribution .

6. The two basic classes of warheads are:

   A. Fuzed

   B. Nonfuzed

7. Nonfused warheads are referred to as penetrator warheads or kinetic energy penetrators.

8. The four major types of high explosive warheads are:

A. Blast or pressure

B. Fragmentation

C. Continuous rod

D. Shaped charge

9. The damage processes associated with penetrators are:

A. Ballistic impact

B. Penetration

C. Hydraulic ram

D. Ignition

10. Depleted uranium is 50% more dense than lead, increasing its ability to penetrate. Uranium is also pyrophoric, making it an incendiary warhead.

11. The principal damage mechanism of a charged nuclear particle weapon would be incapacitation or death of crewmembers.

12. The general sequence of events of threat operations is:

A. Detection

B. Identification

C. Tracking

D. Fire control solution

E. Launch or firing of threat propagator

F. Guidance of a guided propagator

13. Maximum target detection range is the maximum range at which a target can barely be unambiguously discerned.

14. Maximum effective range is the maximum range at which the propagator can cause damage to an aircraft.

15. Lead angle prediction error is the projectile miss distance resulting from errors in the prediction of the target flight path.

16. The most common guidance systems used by missiles are:

A. Command

B. Beam rider

C. Homing

D. Retransmission

17. The major types of homing systems used today are:

A. Active

B. Semi-active

C. passive

18. The most common control laws used are:

A. Pursuit

B. Lead angle

C. Command-to-line-of-sight

D. Proportional navigation (PRONAV)

19. The three phases of guidance are:

A. Boost phase

B. Midcourse phase

C. Terminal phase

20. The terminal phase requires the highest accuracy and fastest reaction time.

21. The major parts of a typical explosive warhead are:

A. Casing

B. Explosive core

C. Fuze

22. The basic fuzing systems are:

A. Contact (superquick and delay)

B. Proximity (VT)

C. Command detonation

23. The essential elements of a mission-threat analysis are:

A. Define the operational mode required by the specific mission.

B. List the applicable threats and the threat characteristics.

C. Analyze the aircraft operational modes and the threats and determine the encounter conditions.

D. Use the derived encounter conditions as a basis for the required survivability assessment and tradeoff studies.

CHAPTER IV

1. What are the purposes of combat data analysis?

2. If 473 combat sorties and 27 tactics training flights are flown with 11 aircraft lost in combat and one destroyed on a training flight, what is the combat loss rate?

3. What is the best source of cataloged combat data?

4. If the combat loss rate is 2%, what is the probability of surviving 100 combat missions? If the combat loss rate is reduced to 1%, what is the probability of surviving 100 combat missions?

5. (TRUE or FALSE) If the XJ-190 has a combat loss rate of 0.1 and the XJ-222 has a combat loss rate of 0.45, the XJ-190 must be a more survivable aircraft. Justify your answer.

6. What are the two major efforts of the Battle Damage Assessment and Reporting Program (BDARP)?

7. Describe a loss-cause network.

8. What is one purpose of a loss cause analysis?

9. What are the Center for Naval Analysis (CNA) loss-cause categories?

10. Based on recent combat data what are the critical aircraft systems, and what are the most important damage processes?

ANSWERS (CHAPTER IV)

1. The purposes of combat data analysis are to:

   A. Determine the effectiveness of enemy weapon systems

   B. Ascertain the survivability of U. S. aircraft

   C. Determine the effectiveness of survivability enhancement techniques.

2. (1000/473)*(11)=23.2558

   The non-combat flights and losses due to non-combat flights are not considered in the computation.

3. The best source of catalogued combat data is the Combat Data Information Center, Wright-Patterson AFB, Ohio.

4. P<S> (100 flights)=(P<S> of one flight)**100

   (0.98)**100= .1326 = 13.26%

   (0.99)**100= .3660 = 36.60%

   P<S> has increased by a factor of 2.76.

5. FALSE

The intensity of the threat must be considered along with the combat loss rate before a valid comparison of aircraft can be made.

6. The major efforts of the BDARP are:

   A. The collection of combat damage/loss data.

   B. The storage, collation, retrieval, and dissemination of the data through the CDIC.

7. A loss-cause network is a chain of events for all incidents leading to an ultimate loss cause. It shows the progression of failures from initial damage to the ultimate loss cause.

8. A Loss-cause analysis can help in the identification of the critical components of the aircraft.

9. The CNA loss-cause categories are:

   A. Fire intensity

   B. Pilot incapacitation

   C. Pilot error

   D. Explosion

   E. Loss of control

   F. Engine failure/loss of thrust

   G. Loss of stable flight (structural)

   H. Unknown

10. Based on combat data, the critical aircraft systems are:

A. Fuel system

B. Engine

C. Flight controls & hydraulic systems

D. Lubrication system (helicopters)

E. Main rotor (helicopters)

F. Crew

The most important damage processes are:

A. Penetration

B. Ignition

CHAPTER V

1. Define vulnerability.

2. Does vulnerability refer to the aircraft as a whole or to its individual components?

3. Describe the process of vulnerability reduction.

4. What is the first step in a vulnerability reduction study?

5. What are the aircraft kill categories?

6. What are the levels of attrition kill and what are their definitions?

7. Define the term critical component. Give several examples of critical components.

8. Why is a special kill level (forced landing kill) defined for helicopters?

9. What kill level would result from inability of an attack aircraft to lower its landing gear?

10. What are flight essential functions and mission essential functions?

11. What is a failure mode and effects analysis (FMEA)?

12. Describe two failures of a gun subsystem on an attack aircraft, one of which makes it a critical component for an attrition kill and another which would result in a mission abort kill.

13. How does the fault tree analysis (FTA) differ from the failure mode effects analysis ?

14. Of the FMEA and FTA, which identifies the possibility of secondary hazards that can be caused by the primary damage process?

15. What are the fuel system damage-caused failure modes, and what are some of the techniques which can be used to prevent or minimize failure?

16. What are the failure modes of the propulsion system? Suggest some means to prevent them.

17. What are the failure modes of the flight control system, and what vulnerability reduction techniques can be used?

18. What are the failure modes of the power train and rotor blade/propeller system? What vulnerability reduction techniques can be used?

19. What failure modes are associated with the structural system and what vulnerability reduction techniques can be applied?

20. Define the terms redundant and nonredundant when used to categorize critical components.

21. (TRUE or FALSE) An aircraft with two components which perform the same function (for instance two flight control hydraulic systems) is always redundant in that system. Explain your answer.

22. If you are associated with a military aircraft, attempt to list the critical components for your aircraft. Charactorize each critical component as redundant or nonredundant. Attempt to determine any redundant components which have failure modes which in fact make them nonredundant.

23. What is a kill tree?

24. What is the kill expression?

25. Restate the six vulnerability reduction concepts.

26. What are the passive damage suppression techniques? Give examples of each.

27. What are the two general types of component redundancy? Give an example of each.

28. How can component location reduce vulnerability?

29. What are some of the techniques of active damage suppression?

30. What is parasitic armor?

31. How can shielding of components be achieved?

32. Describe some component elimination techniques.

33. What is the difference between ballistically tolerant systems and ballistically resistant systems? Which is preferred?

34. What specific vulnerability reduction techniques can be applied to the crew system?

35. You are flying a single seat scout helicopter which has no redundant components and no critical component overlap. The following data is applicable from one aspect:

critical component:	presented area:	probability of kill given a 7.62mm hit:

pilot	4 sq. ft.	1.0
fuel tank	17 sq. ft.	0.37
engine	8 sq. ft.	0.8
tail rotor gear box	1 sq. ft.	0.6
main rotor gear box	14 sq. ft.	0.15
flight control hydraulic system	3.2 sq. ft.	0.8

Total presented area of helicopter is 155 sq. ft.

What is the vulnerable area of your aircraft for the given aspect? What is the probability of kill given a hit, P<K/H>, for your aircraft?

What is the probability of kill, given a hit on the aircraft, for each individual component (P<k/Hi>)?

What is the probability of survival, P<S>, given one hit?

What is the probability of survival, P<S>, given ten hits?

36. How does the additional of a redundant component alter the computation of vulnerable area, given a single hit?

Consider the scout helicopter in the previous question. It has been retrofitted to a dual engine configuration to enhance its survivability. The only change is the addition of another engine, also 8 sq. ft. in area. There is no component overlap. What is the probability of kill given a single hit P<K/H> now?

37. Consider a light attack aircraft with a digital fly-by-wire flight control system. The following data is available on critical components.

critical component:	presented area:	probability of kill, given a 7.62mm hit:
pilot	4.0 sq. ft.	1.0
fuel system	52.0 sq. ft.	0.26
engine	40.0 sq. ft.	0.6
flight control computer	3.0 sq. ft.	0.7

The flight control computer complately overlaps the fuel tank. What is the vulnerable area of the aircraft?

38. Write a kill expression for a helicopter with the following critical components:

non-redundant components:	redundant components:

DRIVE TRAIN	PILOT/COPILOT
FUEL TANK	#1 ENGINE/#2 ENGINE
HYDRAULIC PUMP	#1 WIDGET/#2 WIDGET/#3 WIDGET
THINGUS	(Kill will result if any two of three widgets are killed)

39. Draw the kill tree for the helicopter in problem 39.

40. Briefly describe several of the techniques used to evaluate vulnerability to internally detonating warheads.

41. What are the damage mechanisms associated with externally detonating warheads?

42. Your aircraft is subjected to an external warhead burst, and 87 penetrators strike your aircraft. Each penetrator has a probability of kill given a hit of 0.02. What is your probability of survival? Work the problem two ways and compare your answers. Assume that the effect of each penetrator is independent of the others.

43. What variables must be considered in the evaluation of externally detonating warheads to accurately predict the probability of aircraft kill?

44. What are the major categories of computer programs for vulnerability assessment?

45. What is an Endgame program?

46. What two methods can be used to compute the probability of kill of an aircraft with redundant components, given multiple hits?

47. Given the kill transition matrix in this chapter, what is the probability of kill given one hit? Given ten hits? Given twenty-five hits? (A programmable calculator or computer solution is highly recommended.)

48. What are the measures of vulnerability?

49. If the XB-148 has a probability of kill given a hit of 0.1 and the XB-888 has a probability of kill given a hit of 0.17, which is more vulnerable? Explain your answer.

50. What items of information are necessary to conduct a vulnerability assessment?

51. What are the three component kill criteria?

52. List and briefly describe the computer programs known as shotline generators.

53. List and briefly describe the computer programs known as vulnerable area routines.

54. List and briefly describe the computer programs known as Endgame programs.

55. Compute the vulnerability of a redundant component A/C.

A. Consider a single engine helicopter that has five critical components that are vulnerable to a 12.7mm API projectile. These components are two fuel tanks, the pilot, the engine, the tail rotor/drive shaft. Assume that these five components are non-redundant and have the following characteristics:

COMPONENT	PRESENTED AREA	P<K/H>
Fuel Tank #1	10 sq. ft.	0.2
Fuel Tank #2	8 sq. ft.	1.0
Tail Rotor/Drive	10 sq. ft.	1.0
Pilot	4 sq. ft.	1.0
Engine	12 sq. ft.	0.5

The total presented area of the helicopter is is 200 sq. ft.

Compute the vulnerable area and the P<K/H> of the aircraft.

B. Suppose a cross-cver feed system is added, making the fuel tanks redundant components. compute the probability the aircraft is killed after taking one hit, after three hits, after six hits and after ten hits. Plot the cumulative probability of kill versus the number of hits.

C. Plot the number of aircraft saved in 1000 sorties because of this modification. Assume each sortie consists of one hit, of three hits, of six hits, and of ten hits.

56. You are the pilot of a single engine attack aircraft which has two cockpit positions. You have five critical components vulnerable to 50 cal. API projectiles. These components are two pilots, the engine, flight control computer, and a fuel tank which straddles the engine inlet duct. The following data is pertinent:

COMPONENT	PRESENTED AREA	PROBABILITY OF KILL, GIVEN A HIT ON THE COMPONENT
PILOT #1	4.0 sq. ft.	1.0
PILOT #2	4.0 sq. ft.	1.0
ENGINE	16.0 sq. ft.	0.6
FUEL TANK	22.0 sq. ft.	0.3
FLIGHT CONTROL COMPUTER	3.0 sq. ft.	0.9

Total presented area is 185.0 sq. ft.

Develop the transition matrix and evaluate probability of kill of the aircraft for one, five, and ten hits.

It has been proposed that the aircraft be operated single piloted. Comment on the benefits and costs given one, five, and ten hits. Assume that the size of the aircraft does not change.

ANSWERS (CHAPTER V)

1. Vulnerability refers to the inability of an aircraft to withstand one or more hits by the various damage mechanisms-to its liability to damage or destruction when hit by enemy fire.

2. Vulnerability refers both to the individual components and to the aircraft as a whole. Each component contributes in some measure to the overall vulnerability of the aircraft.

3. Vulnerability reduction is the reduction of the likelyhood that one or more of the critical components of the aircraft will be killed if the aircraft is hit.

4. The first step in a vulnerability reduction study is the identification of those components whose damage or loss could lead to an aircraft kill.

5. The aircraft kill categories are:

A. Attrition kill

B. Mission abort kill

C. Forced landing kill

6. The attrition kill levels are:

A. KK kill - Damage that will cause an aircraft to fall out of control immediately upon being hit.

B. K kill - Damage that causes an aircraft to fall out of control within 30 seconds after being hit.

C. A kill - Damage that causes an aircraft to fall out of control within 5 minutes after being hit.

D. B kill - Damage that causes an aircraft to fall out of control within 30 minutes after being hit.

7. A critical component is a component which, if damaged or destroyed, would yield a defined or definable aircraft kill level. Examples: Pilot, engine, flight control system, etc. for an A kill.

8. The ability of a helicopter to safely land with a variety of damage modes which would cause a fixed wing aircraft to be lost requires the special forced landing kill level to be defined for helicopters. These modes include (but are not limited to) loss of engine power, massive fuel leakage, difficulty in operating controls, and slow leakage of engine lubrication oil, flight control hydraulic oil, etc.

9. The inability of an aircraft to lower its landing gear would result in an attrition kill due to its inability to land without major damage.

10. Flight essential functions are those system and subsystem functions required to enable an aircraft to sustain controlled flight. Mission essential functions are those system and subsystem functions required to enable an aircraft to perform its designated mission.

11. An FMEA is a proceedure that (1) identifies and documents all failure modes of a component or subsystem and (2) determines the effects of each failure mode upon the capability of the system or subsystem to perform its essential functions.

12. An attrition kill might result if penetration of the ammunition drum by an API projectile caused detonation of ammunition in the drum, resulting in major structural damage. Mission abort kill might result if the drum was distorted enough to prevent ammunition from feeding.

13. An FMEA is a bottom-up approach. Failure of a component is assumed (for instance, loss of the flight control hydraulic actuator) and the consequences of that failure are identified (loss of control).

A fault tree analysis is a top-down approach. The undesired event is defined, then the events and/or combinations of events that can result in that event are identified. (Loss of control is defined, and loss of the flight control hydraulic actuator is identified as a potential cause.)

14. The FMEA identifies secondary hazards as well and primary hazards.

15. Damage caused failure modes	Vulnerability reduction techniques:
A. Fuel supply depletion	-Self sealing tanks -Multiple isolated tanks -Reduced presented area -Low ullage pressure -Accurate fuel gageing -Fuel crossfeed and bypass systems
B. In-tank fire and explosion	-Maintain nonexplosive atmosphere in tank -Inert atmosphere (nitrogen) -Vent to remove fuel vapors -Fire suppressing atmosphere (HALON 1301)

	Foams
	-Use antimisting fules
C. Void space fire and explosion	-Drain holes to allow leaked fuel to escape
	-Vent voids to remove fuel vapors
	-Active fire extinguishing systems
	-Use antimisting fuels
	-Use powder pack/purge mats
D. Sustained exterior fire	-Prevent leakage from fuel systems
	-Eliminate "flame holder" projections
E. Hydraulic ram	-Maximize volume of fuel in tanks
	-Provide smooth, simple contours for fuel tank walls
	-Avoid direct fuel tank/engine inlet interface
	-use tear resistant/energy absorbing wall materials

16. Propulsion system failure modes:	Vulnerability reduction techniques:
A. Fuel ingestion	-Avoid direct fuel tank/inlet interface -Use fuel from tanks near inlets before entering combat
B. Foreign object ingestion	-Avoid direct fuel tank/inlet interface -Use ballistically tolerant materials which yield little or no debris to form ducts -use fuel from tanks near inlets before entering combat
C. Inlet flow distortion	-Prevent hydraulic ram damage to inlets
D. Lubrication starvation	-Minimize presented area of lubrication system components -Use self sealing or ballistically tolerant components -Armor or shield components

	-Use bypass lines to isolate or minimize leakage
17. Control system failure modes	Vulnerability reduction techniques
A. Disruption of control signal path	-Ballistically resistant or tolerant control system components
	-Redundant, separate control signal paths
	-Minimize presented area of control signal path (fly-by-wire vice pushrods)
	-colocate servovalves on servoactuators
B. Loss of control power	-Redundant, separate control power systems
	-Backup manual control systems where practicable
C. Loss of aircraft motion sensor data	-multiple sensors
	-Analytic redundancy utilizing digital filters
D. Damage to control	-Damage tolerant control

surfaces and hinges	surfaces and hinges -Multiple hinges -Alternate sources of control (flaps as backup roll control) -Fail-safe surfaces (lock to level flight vice hardover)
E. Hydraulic fluid fires	-Use less flamable hydraulic fluid -minimize leakage -use lower pressure systems (less atomization of fluid) -Use electrical actuators to replace hydraulics
18. Power train & propeller/ rotor blade system failure modes	Vulnerability reduction techniques
A. Loss of lubrication	-Minimize vulnerable area of lubrication system -self sealing tanks and lines -Grease lubrication systems to eliminate exterior lines

B. Mecanical/structural failure

- -Ballistically tolerant drive shafts, bearings, and supports
- -Balistically tolerant rotor blades and propellers
- -Redundant load paths

19. The failure modes associated with the structural system are:

    A. Structural removal

    B. Pressure overload

    C. Thermal weakening

    D. Penetration

    The techniques used to minimize damage are:

    A. Multiple load paths

    B. Fail safe design

    C. Crack stoppers

20. A nonredundant component is a component, the damage or loss of which will result in the loss of an essential function such as lift, thrust, etc.

A redundant component is a component, the damage or loss of which will not result in the loss of an essential function.

21. FALSE. If, for instance, both hydraulic systems are fed from a common reservoir, loss of one system due to a leak

and subsequent loss of fluid would result in the loss of both hydraulic systems.

22. (Various)

23. A kill tree is a visual illustration of the critical components of an aircraft and the contributions of component redundancy.

24. The kill expression is a logical statement using the logical (.AND.) and (.OR.) statements to convey the same critical component and redundancy information that the kill tree contains.

25. The vulnerability reduction concepts are:

A. Component redundancy

B. Component relocation

C. Passive damage suppression

D. Active damage suppression

E. Component shielding

F. Component elimination

26. Some techniques of passive damage suppression are:

A. Damage tolerance

B. Ballistic tolerance

C. Delayed failure

D. Fail-safe response

27. The two general types of component redundancy are:

A. Total redundancy, such as dual flight control hydraulic systems.

B. Partial redundancy, such as use of differential flaps as backup roll control devices.

28. Component location can reduce vulnerability in the following ways:

A. Non-critical components can be positioned to shield critical components.

B. Redundant components can be widely separated to insure single hit redundancy.

C. Critical components can be overlapped or tightly grouped to minimize the presented vulnerable area.

D. Components can be isolated to reduce the possibility of cascading dmage.

29. The following are examples of active damage suppression techniques:

A. Fire detection and extinguishing systems.

B. Alerting systems which can warn of low fluid levels, etc. in time to allow securing of the system without damage.

C. Hydraulic fuses which can isolate a leaking portion of a system without requiring that the entire system be secured.

30. Parasitic armor is armor which does not contribute to the structural strength of the aircraft.

31. Components can be shielded by:

   A. Parasitic armor (including body armor for flight crew)

   B. Integral armor

   C. Other components

32. Some component elimination techniques are:

   A. Replace fuel boost pumps with a suction feed system.

   B. Replace oil pumps and coolers with a grease lubrication system.

   C. Use manual flight controls vice power boosted systems.

   D. Use fly-by-wire or optics vice mechanical pushrods.

   E. Jetison external fuel tanks prior to entering combat to lower vulnerable area and improve performance.

33. A ballistically resistant system is one designed to "repel" the damage mechanism, as armor would. A balistically tolerant system is one designed to "bend" with the

damage and still operate. For example, large diameter, thin walled control rods. Ballistic tolerance is usually to be preferred, since it will often achieve the same result with a significantly lower weight penelty.

34. The following vulnerability reduction techniques can be applied to The crew system:

A. Shield the crew using components or armor.

B. Provide ventilation/oxygen to minimize the effects of smoke and toxic fumes.

C. Reduce pilot workload which would distract the pilot from combat mission performance.

35.

component	presented area	probability of kill, given a hit P<k/hi>	vulnerable area <A/vi>
pilot	4.0 sq. ft.	1.0	4.0 sq. ft.
fuel	17.0 sq. ft.	0.37	6.3 sq. ft.
engine	8.0 sq. ft.	0.8	6.4 sq. ft.
TRGB	1.0 sq. ft.	0.6	0.6 sq. ft.
MRGB	14.0 sq. ft.	0.15	2.1 sq. ft.
flt controls	3.2 sq. ft.	0.8	2.56 sq. ft.

Vulnerable area A<V> =			21.95 sq. ft.

Aircraft probability of kill given a hit

P<K/H>=(21.95)/(155)=0.1416

Component probability of kill given a hit P<k/hi>

pilot: A<vi>= 4/155 = 0.025806

fuel sys: A<vi>= 6.29/155 = 0.040580

engine: A<vi>= 6.4/155 = 0.041290

TRGB: A<vi>= 0.6/155 = 0.00387

MRGB: A<vi>= 2.1/155 = 0.01355

flt.controls: A<vi>= 2.56/155 = 0.01652

Probability of survival given one hit

P<S>=(1-P<K>)=(1-0.14160)=0.8584

Probability of survival, given 10 hits:

P<S> = (1-P<K>)**10=0.21722

36. The redundant components do not contribute to the vulnerable area for a single hit if there is no overlap of redundant components.

Probability of kill given a hit P<K/H>= (21.95-6.4)/155 = 0.1003

37. A<vi>(pilot) = 4.0*1.0 = 4.0 sq. ft.

A<vi>(engine) = 40.0*0.6 = 24.0 sq. ft.

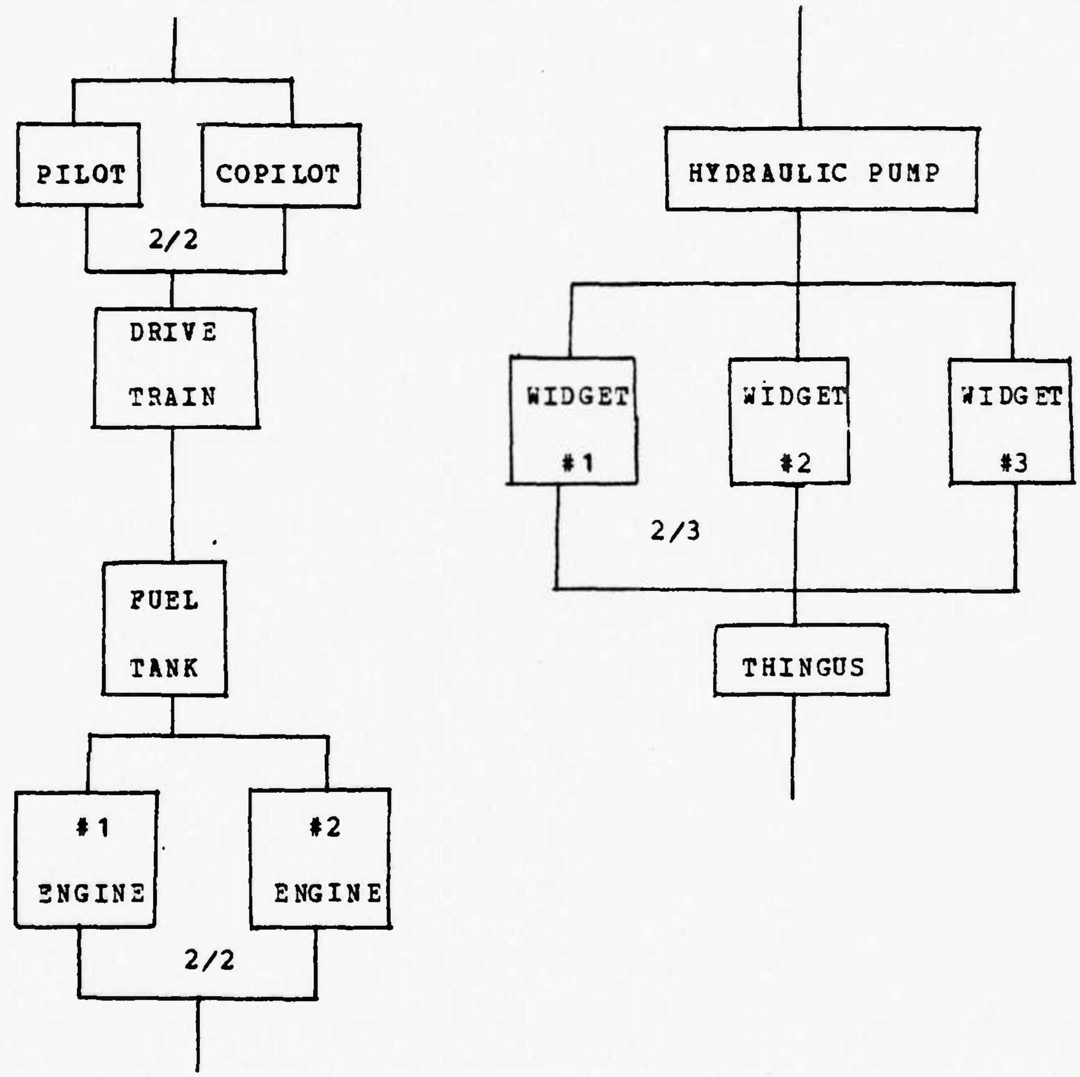
A<vi>(fuel tank) = (52.0-3.0)*0.26 = 12.74 sq. ft.

The area of the flight control computer is subrtacted from the area the fuel tank, since any shotline through this area will result in kill due to the vulnerability of the flight control computer.

38. The kill expression is:

(PILOT .AND. COPILOT) .OR. (DRIVE TRAIN) .OR.
(FUEL TANK) .OR. (#1 ENGINE .AND. #2 ENGINE) .OR.
(HYDRAULIC PUMP) .OR. (WIDGET #1 .AND. WIDGET #2) .OR.
(WIDGET #2 .AND. WIDGET #3) .OR. (WIDGET #1 .AND.
WIDGET #3) .OR. (THINGUS).

39. The kill tree is:



40. Two techniques to evaluate vulnerability to internally detonating warheads are:

A. Treat the HE round as a penetrator but use an expanded vulnerable area (beyond their actual size) for the critical components.

B. The point burst approach involves dividing the aircraft into various segments and evaluating the probability of kill given detonation in each segment. The probability of kill given a hit is the product of the probability of kill given a hit for each segment times the probability of hitting that segment.

41. The damage mechanisms associated with externally detonating warheads are:

A. Blast

B. Fragments

C. Incendiary particles

42. P<S> = (1-P<K>)**n

P<S> = (1-.02)**87

P<S> = (.98)**87

P<S> = 0.1725

Alternatively, using the approximation,

P<S> = 1-(1-P<K/H>)**n = 1-exp(-n*P<K/H>)

P<S> = (approximately) 1-exp(-n*P<K/H>)

P<S> = (approximately) exp(-87*(0.02))

P<S> = (approximately) 0.1775

43. The following must be considered in a missile/aircraft encounter:

A. Fragment static velocity

B. Fragment static spray angle

C. Warhead attitude

D. Aircraft attitude

E. Encounter velocity

F. Encounter geometry (tailchase? head on?)

44. The major categories of computer programs for vulnerability assessment are:

A. Shotline generators

B. Vulnerable area routines

C. Internal burst routines

D. Endgame programs

45. An Endgame program describes an encounter between an aircraft and an HE warhead with a proximity fuze.

46. The two methods used to compute probability of kill of an aircraft with redundant components given multiple hits are:

A. The kill tree diagram

B. The state transition matrix

47. Probability of kill, given one hit:

0.0733 +0.0 = 0.0733

Probability of kill, given ten hits:

0.45442 + 0.0307515 = 0.76194

Probability of kill, given twenty-five hits:

0.550599 + 0.435863 = 0.98645

48. The measures of vulnerability are the vulnerable area and the probability of kill given a hit or detonation.

49. Probability of kill given a hit is the measure of vulnerability, but no valid comparison can be made useing these values. The vulnerable area of each aircraft must also be compared. An aircraft which has a low probability of kill given a hit and a relatively large presented area may in fact be more vulnerable (have a larger vulnerable area) than an aircraft with a higher probability of kill given a hit with a smaller vulnerable area.

50. A vulnerability assessment requires:

A. A selection of the aircraft kill levels or categories to be assessed.

B. An assembly of the technical and functional descriptions of the aircraft.

C. A determination of the critical components of the aircraft.

D. A determination of the threats the

system will encounter

E. A determination of the type and ammount of damage required to kill each component.

F. The computation of the appropriate vulnerability measures for the components and for the the aircraft based on the threat selected.

51. The three component kill criteria are:

A. Probability of component kill given a hit

B. The area removal criterion

C. The energy density criterion

52. The shotline generators are:

A. MAGIC - Uses combinatorial geometry and basic body shapes (boxes, spheres, etc) to model component geometries.

B. GIFT - An improved MAGIC with simpler input and more efficient computation.

C. SHOTGEN - Similar to MAGIC but uses flat triangular patches to model component surfaces.

D. FASTGEN - A more recent version of SHOTGEN.

53. The detailed vulnerable area routines are:

A. VAREA - Conducts vulnerability analyses of systems subjected to single ftagments and penetrators.

B. VAREA02 -Evolved from VAREA, adding a penetration mode, an air gap fire model, and a redundant components model.

C. COVART - Adds helicopter vulnerable area routines to VAREA02 and includes a battle damage damage repair time model.

A simplified detailed area routine exists:

D. COMVAT - A vulnerable area routine which uses average shielding values for components vice shotlines.

54. The Endgame programs are:

A. SESTEM II - Evaluates the terminal effects of a non-nucluar missiles against aerial targets. Computes with respect to a direct hit, fragment damage, and blast.

B. SCAN - Predicts the probability that an aircraft will survive an attack by a missile armed with a warhead. Allows various fragment sizes and shapes. Has graphics capabilities for evaluation of input and output data.

C. ATTACK - Predicts the ability of a missile to attack and destroy an airborne target. Allows various fuzing options.

D. REFMOD (MECA) - Allows selection of warhead type and fuze routines. Components are modeled by various geometrical shapes.

55.

A.

COMPONENT	PRESENTED AREA A(pi)	PROBABILITY OF KILL, GIVEN A HIT (P<K/hi>	VULNERABLE AREA A<vi>
#1 FUEL TANK	10 sq. ft.	0.2	2 sq. ft.
#2 FUEL TANK	8 sq. ft.	1.0	8 sq. ft.
TAIL/ROTOR DRIVE	10 sq. ft.	1.0	10 sq. ft.
PILOT	4 sq. ft.	1.0	4 sq. ft.
ENGINE	12 sq. ft.	0.5	6 sq. ft.

Vulnerable area (total) = 30 sq. ft.

P<K/H> = 0.15 = (200 sq. ft.)/(30 sq. ft.)

B. Transition matrix symbols used:

KNRC = Probability of kill of a non-redundant component

KFT1 = Probability of kill of #1 fuel tank

KFT2 = Probability of kill of #2 fuel tank

KFT = Probability of kill of both fuel tanks

NK = Probability of no kill

TRANSITION MATRIX - REDUNDANT AIRCRAFT

KNRC	KFT1	KFT2	KRC	NK
1.0	0.1	0.1	0	.1
0	.86	0	0	.01
0	0	.89	0	.04
0	.04	.01	1	0
0	0	0	0	.85

C. Aircraft saved per 1000 sorties due to fuel system change:

NO. OF HITS:	P<K/H> REDUNDANT	P<K/H> NON-REDUNDANT	A/C SAVED PER 1000 SORTIES
1	.1	.15	50
3	.2731	.3859	116.4
6	.4756	.6229	147.3
10	.6638	.8031	139.3

56.

COMPONENT	A<Pi> (sq. ft.)	P<K/hi>	A<Vi> (sq. ft.)	P<K/Hi> (AIRCRAFT)
PILOT #1	4.0	1.0	4.0	0.0216216
PILOT #2	4.0	1.0	4.0	0.0216216
ENGINE	16.0	0.6	9.6	0.0518919
FUEL TANK	22.0	0.3	6.6	0.0356756
FLT. CONTROL COMPUTER	3.0	0.9	2.7	0.0145946

Vulnerable area = 26.9 sq. ft.

Probability of kill given a hit = 0.14540540

185 - 26.9 = 158.1 sq. ft.

185 - 49 = 136 sq. ft.

B. Transition matrix symbols used:

Kp1 = Probability of kill of pilot no. 1

Kp2 = Probability of kill of pilot no. 2

Knrc = Probability of kill of a non-redundant component

Krc = Probability of kill of a redundant componant

Nk = Probability of no kill

TRANSITION MATRIX USED:

Knrc	Kp1	Kp2	Krc	Nk
1	0.1022	0.1022	0	0.1022
0	0.8762	0	0	0.0216
0	0	0.8726	0	0.0216
0	0.0216	0.0216	1	0
0	0	0	0	0.8546

For one hit, P<K> = 0.10216

For five hits, P<K> = .415782 + 7.07884E-3 = 0.42286

For ten hits, P<K> = .653718 + 2.05506E-2 = 0.67427

For the case where the aircraft is flown single piloted:

COMPONENT	A<Pi> (sq. ft.)	P<K/hi>	A<Vi> (sq. ft.)
PILOT #1	4.0	1.0	4.0
ENGINE	16.0	0.6	9.6
FUEL TANK	22.0	0.3	6.6
FLT. CONT. COMPUTER	3.0	0.9	2.7

Total presented area is still 185.0 sq. ft.

Total vulnerable ares is 22.9 sq. ft.

P<K/Hi> = 22.9 / 185 = .1238

For one hit, P<K/H> = 0.12378 P<S> = 0.87622

For two hits, P<K/H> = 0.48352 P<S> = 0.51648

For ten hits, P<K/H> = 0.73325 P<S> = 0.26675

No. of hits	Ammount second pilot lowers P<K/H>
1	0.021521
5	0.060657
10	0.058976

	OPERATED SINGLE PILOTED	OPERATED DUAL PILOTED	
HITS	PILOTS/AIRCRAFT LOST	PILOTS LOST	AIRCRAFT LOST
1	123.8	123.8	102.2
2	232.2	269.7	194.8
3	327.3	375.9	278.7
4	410.6	466.6	354.5
5	483.5	544.2	422.9
6	547.4	610.4	484.4
7	603.5	567.1	539.8
8	652.6	715.5	589.6
9	695.6	756.9	634.3
10	733.2	792.2	674.3

C. AIRCRAFT SAVED vs. PILOTS LOST

HITS	AIRCRAFT SAVED	ADDITIONAL PILOTS LOST
1	21.6	0
2	37.4	37.5
3	48.6	48.6
4	56.0	56.0
5	60.7	60.7
6	63.0	63.0
7	63.6	63.6
8	62.9	62.9
9	61.3	61.3
10	59.0	59.0

For each additional pilot lost, one additional aircraft returns from the mission.

TRADEOFF: 1 FOR 1

CHAPTER VI

1. What is a measure of susceptibility, and what major items is it dependent upon?

2. What are the important features of the threat?

3. What important factors are associated with the aircraft in an encounter with a threat?

4. What is a susceptibility assessment? What categories does it divide events into?

5. What is the purpose of an essential elements of assessment (EEA)?

6. Define aircraft signatures and list those mentioned in the text.

7. What must be considered in addition to the aircraft signatures when evaluating the ability to detect or track an aircraft?

8. What is radar cross section? How is it expressed?

9. What basic relationships can be formulated between aircraft size and radar cross section?

10. What variables affect the RCS of an aircraft?

11. What is perhaps the most important design feature to avoid in designing an aircraft to minimize RCS?

12. What is target glint?

13. What "problem areas" require a great deal of attention from the standpoint of minimizing RCS?

14. What methods are available to determine radar cross section?

15. Where would you most probably be able to find tabulated RCS data for aircraft?

16. What are the major sources of infrared radiation from aircraft?

17. What part of the electormagnetic spectrum encompasses infrared radiation?

18. What determines the frequency of the peak IR radiation emitted by a solid body?

19. If the afterburner of your aircraft increases the tail pipe temperature by a factor of two, what does this do to the intensity of IR radiation from the tail pipe?

20. What are the main contributers to the IR signature of the exhaust plume? What is the major contributor? At what wavelength?

21. What is the best source of DOD infrared and electro-optical information?

22. What are the visual observables? Why are visual signatures important?

23. What are the four parameters that influence detectibility of visual signatures? Define them.

24. What factors influence the aural detectibility of an aircraft?

25. What are the principal sources of aircraft noise?

26. What is the "end product" or desired information derived by an aircraft detection and tracking system?

27. You are flying thirty kilometers from a fire control radar mounted four meters above the ground. At what altitude must you fly to be below the radar horizon of the fire control radar?

28. In the radar range equation, what variables does the aircraft designer have control over? What is the functional relationship between detection range and these variables?

29. If you succeed in doubling the system noise of a radar via electronic countermeaseures, by what amount do you decrease detection range? What would you have to do to system noise to halve the detection range?

30. What is the maximum unambiguous range im meters of a radar with a pulse repetition rate (PRF) of 10,000?

31. What is the probability of detection of an aircraft scanned ten times by a radar system if the probability of detection is 0.4 for each scan?

32. What general characteristics would you expect a search radar to have?

33. What general characteristics would you expect a fire control radar to have?

34. What are the general techniques used by fire control (weapon control) radars to track in azimuth?

35. What is the "probable error" of a radar system?

36. What are the "systematic errors" of a radar system? What sources of random errors degrade radar tracking accuracy?

37. What factors in the lock-on range equation for an infrared detector does the aircraft designer/user have some control over? What are the functional relationships?

38. You have selected afterburner in your aircraft to more rapidly depart the combat zone. Your exhaust plume is 1.6 times its former temperature. How has your IR detection range been affected?

39. What techniques are used by IR seekers to track targets?

40. What is a visually directed weapon system? List some examples of visually directed weapon systems.

41. Where are theoretical studies of detection and tracking by human operators using visual tracking devices conducted?

42. What is attenuation of IR radiation?

43. What radar system deceptive countermeasures are used?

44. What are expendables? How are they used and how do they work?

45. What is a radar noise jammer? Describe the three types.

46. What are the factors that impose practical limits on radar and IR detection range?

47. You are designing a fire control radar for a mobile gun system which must have a maximum unambiguous range of ten kilometers You must also have a range resolution of of ten meters, and you are limited (by your cooling system) to an average power of ten watts. Specify the maximum pulse repetition frequency and maximum pulse length you can use. What will your peak power be?

48. As an aircraft designer, you inadvertently created a triangular corner reflector by using a radar transparent bomb bay door to cover a rectangular metal bomb bay, which has a characteristic dimension of 60 cm. What is the radar cross section of this area to a 3 cm radar?

49. What is the maximum pulse repetition frequency that can be used on an air search radar which must have an unambiguous range of 150 nautical miles? What duty cycle would result if your minimum detection range was five miles? If the radars peak power is one megawatt (10**6 watts), what is the average power?

50. You are trying to develop a radar to warn of incomeing AAA, and you decide that to get adequate return you must use a wavelength of 0.8 cm. What would the operating frequency of the radar be?

ANSWERS (CHAPTER VI)

1. A measure of susceptability is probability of hit, P<H>, and it is dependent upon three things:

A. The scenario

B. The threat

C. The aircraft

2. The important features of the threat are:

A. Threat characteristics

B. Threat operations

C. Threat lethality

3. The important factors associated with the aircraft in an encounter with a threat are:

A. Aircraft observables or detectable signatures

B. Countermeasures used

C. Aircraft performance capabilities

4. A susceptibility assessment is a modeling of the sequence of events and elements in the aircraft/threat encounter until a hit on the aircraft occurs. The events can be divided into two categories:

5. The purpose of an EEA is to determine which of the features or elements of an aircraft/threat encounter are important and which can be eliminated from the assessment.

A. Detection/tracking/fire control doctrine/launch & guidance of missiles or firing of AAA projectiles, or firing of radiation beams. (Simulation or flyout model)

B. Detonation/impact of warhead/penetrator or radiation. (Includes terminal encounter geometry, fuzing capability & logic, damage mechanism generation and propagation.)

6. Aircraft signatures are those characteristics that can be used by the threat systems for detection and tracking.

The four electromagnetic signatures are:

A. Radar

B. Infrared

C. Visible

D. Ultraviolet

Another signature is:

E. Aural

7. In addition to aircraft signatures, any intentional or inadvertant emissions from the aircraft can be important, especially for detection.

These include (but are not limited to):

A. Voice or data transimission via radio

B. Navigation radar

C. TACAN (Tactical Air Navigation)

D. Aircraft lights

8. Radar cross section is a measure of the amount of the incident radar signal which is reflected toward the receiving antenna. It is expressed in either area (square meters) or in decibels (dB), usually referenced to one square meter.

9. No simple relationship can be stated to correlate aircraft size and radar cross section.

10. The following variables affect radar cross section:

A. Aircraft size

B. Angularity of surface junctures

C. Aircraft attitude

D. Aircraft configuration

E. Aircraft materials

F. Wave length of incident radar signal

G. Polarization of incident radar signal

11. The corner reflector behaves very much like a mirror to radar waves over a large range of aspect angles and hence

should be avoided whenever possible. In particular, the three corner right angle reflector is capable of returning a radar signal over an extremely large range of aspect angles. A single three corner reflector can display a very high RCS over one eighth of the entire aspect of the aircraft.

12. Target glint, also known as bright spot wander, is the motion of the aparent centroid of the RCS about the aircraft as the aspect angle varies slightly. It is caused by constructive and destructive interference of the individual radar echos returning from the various surfaces of the aircraft.

13. The areas which require a great deal of attention to reduce radar cross section are:

A. Bomb bays

B. Jet engine inlets and nozzles

C. Fuselage-wing intersections

D. Fuselage-empenage intersections

E. Wing-pylon intersections

F. Cockpit

G. Antennas and antenna compartments

H. Main and tail rotor heads

I. Bomb bay door-fuselage intersections

14. there are several methods to determine radar cross section:

A. Analytic computation (exact solution)

B. Analytic solution of a mathematically simplified model

C. Experimental measurement using flight test aircraft

D. Static testing of full size aircraft

E. Static testing of reduced size models

15. One of the most complete collections of RCS data is the Air Force Electronic Warfare Center (AFEWC), Kelly AFB, San Antonio, Texas.

16. The major sources of infrared radiation from aircraft are:

A. Hot parts of airframe and propulsion system

B. Reflected solar radiation

C. Hot engine exhaust plume

17. Infrared radiation occurs in the electromagnetic spectrum at 0.77 to 1000 microns.

18. The frequency of the peak IR radiation is a function of the temperature of the radiating body.

19. The intensity of the total radiation emitted from a body is a function of temperature raised to the fourth power. Power = f(T**4), therefore, (2**4 = 16) you are emitting 16 times as much IR power.

20. The main contributors to the IR signature of the exhaust plume are water vapor and carbon dioxide. The carbon dioxide is the major contributor and radiates at a wavelength of 4.2 to 4.7 microns.

21. The best source of DOD IR and electro-optical information is the Infrared Information and Analysis Center (IRIA), Environmental research institute of Michigan, Ann Arbor, Michigan.

22. The visual observibles are:

A. Smoke

B. Contrails

C. Sun glint

D. Engine exhaust glow

Often these observables can be seen befor the aircraft itself is visible, allowing additional optical tracking time to arrive at a fire control solution.

23. The four parameters that influence detectibility are:

A. LUMINANCE: the radiance or power per unit solid angle per unit area of an object weighted by the luminosity function of a standard observer.

B. CHROMATICITY: the chromatic contrast of a body, irrespective of its luminance. A light blue aircraft seen against white clouds might have the same luminance as the clouds, but can be easily seen, because of the difference in chromaticity.

C. CLUTTER: the changing visual bachground makes an aircraft more easily seen.

D. MOVEMENT: the motion of an aircraft,particylarly that of rotor blades, can be an important factor in detectibility of aircraft.

24. The aural detectibility of an aircraft is influenced by:

A. The intensity and spectrum of noise generated

B. The spatial pattern of noise radiation

C. The distance between aircraft and observer

D. Atmospheric refraction and scattering effects

E. The level and spectrum of background noise near the observer

25. The principal sources of aircraft noise are:

A. Propeller/rotor blade rotational and vortex noises

B. Engine inlet/exhause noises

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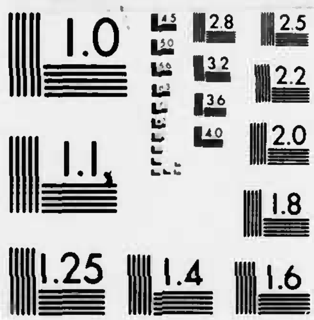

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

C. Engine combustion/rotary noises

D. Airframe aerodynamic noises

26. The end product of aircraft detection and tracking is a relatively accurate determination of the aircraft's location in azimuth, elevation, velocity, range and heading as a function of time.

27. Radar horizon = 6.5*((h<ant>)**0.5 +(h<ac>)**0.5)

ht of aircraft = (R<H>/6.5 - ((h<ant>)**0.5)**2

ht of aircraft = (30/6.5 - 2)**2

You must fly below 6.8 meters above the ground to avoid detection.

28. The aircraft designer has some control over radar cross section (RCS) through design considerations and radar system noise (N) via electronic countermeasures.

Range = f((RCS)**.25, (1/N)**.25)

29. Doubling system noise reduces maximum detection range by a factor of 0.84.

Range = f((1/N)**.25) = (1/2)**.25 = 0.8409

To solve for noise to halve maximum detection range, solve the functional relationship for noise:

range = f((1/N)**.25)

0.5 = f((1/N)**.25

N = 16

You must increase system noise by a factor of 16 to halve detection range.

30. Given a PRF of 10,000, the maximum unambiguous range of a radar is:

R<u> = c/(2*PRF)

R<u> = 3.0**10^{8} m/s / 20,000 pps

R<u> = 15,000 meters

R<u> = 15 kilometers

31. The cumulative probability of detection for ten scans is one minus the product of the probabilities that the aircraft will not be detected on each scan.

P<cd>(S) = 1-(1-P<ds)**S

P<cd> = 1-(1-0.4)**10 = 1-(0.6)**10 = 1-(0.0060) = 0.9940

32. A search radar would have:

A. Long range (implies low PRF)

B. High power (long pulse, implies poor range resolution)

C. Low antenna rotation rate (to put many pulses on the target to maximize the probability of detection)

D. Ability to track many targets at one time

33. A fire control radar would have:

A. Relatively short range (high prf)

B. High angular resolution

C. Short pulses (good range resolution)

D. Track few (or one) targets at a time

E. May use doppler tracking

34. The general tracking techniques used by fire control radars are:

A. Conical scan

B. Monopulse

C. Track while scan

35. Probable error is the magnitude of that deviation error such that one half of the errors are larger and one half of the errors are smaller than the probable error.

36. The systematic errors of a radar are:

A. Antenna misalignment

B. Servo lag

C. Multipath

The causes of random errors in the radar are:

A. Receiver noise

B. Tracking jitter

C. Target glint

37. The designer/operator of the aircraft has some control over the IR signature.

Lock on range = f(IR signature (watts/stearadian))**0.5

38. Increaseing your exhaust plume temperature by a factor of 1.6 will increase your detection range by a factor of 1.265.

R(lo) = f(P(i))**0.5 = (1.6)**0.5 = 1.2649

39. Scanning techniques used by IR seekers are:

A. Reticle trackers

1. Spinning reticles
2. Stationary reticles

B. Scanning trackers

1. Rosette trackers
2. Crossed array trackers
3. Raster trackers
4. Rotating linear arrays

40. A visually directed weapon system is one which uses the human eye as either a primary or backup detection or guidance system.

Some examples are:

A. Iron sights on small arms

B. Stereoscopic rangefinders

C. Electro-optical imaging equipment, such as low light level tv.

41. Studies using human trackers are conducted at: The Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

42. Attenuation is the decrease in intensity of IR radiation between the emitter and the detector. It is a function of both spherical spreading (1/r**2) and reflection, scattering, and absorption by gasses and water droplets in the atmosphere.

43. There are four basic categories of DECM techniques:

A. Time Modulated DECM

1. Range-Gate Pull-Off

2. Multiple False Targets

B. Amplitude Modulation DECM

1. Countdown

2. Cover Pulse

3. Scan Rate Modulation

a. Inverse Conscan

C. Phase of Frequency Modulation DECM

1. Velocity-Gate Pull-Off

2. Cross Eye

D. Polarization Modulation

44. Expendables are IR flares, chaff, and other materials or devices (possibly including small missiles) released, dropped, or launched from aircraft in an attempt to prevent lock-on or break lock-on of a seeker. They work, in the general sense, by attracting attention to themselves and consequently away from the aircraft. Chaff can also be used to screen the movement of aircraft which follow the chaff-laying aircraft.

45. A noise jammer is a device which transmits enough power to drown out the aircraft echo on the radar scope.

The three basic types are:

A. Barrage or broad-band jammers

B. Spot jammers (on a narrow frequency band)

C. Swept jammers

46. Factors which limit the detection range of both radar and IR devices are:

A. Seeker sensitivity

B. Atmospheric losses

C. IR signature or RCS

D. Countermeasures used

E. Relative locations

47. PULSE REPETITION FREQUENCY

R<u> = c/(2*f<r>) ===> f<r> = c/(2*R<u>)

f<r> = (300,000km/sec)/2*(10km) =15,000 pps

RANGE RESOLUTION

Delta R = (c*tau)/2

(tau = pulse width)

2*(10 m) = (300,000,000 m/sec) * tau

tau = 6.67*10**-8 sec

DUTY CYCLE = PULSE WIDTH * PULSE REPETITION FREQUENCY

Duty cycle = (6.67*10**-8)*(15,000) = 0.00100

Pavg = Ppeak*(duty cycle)

Ppeak = Pavg/duty cycle = 10/0.00100 = 10,000 watts

48. Radar cross section for a triangular reflector

RCS = 4*(pi)*(L)**4/3*(wave length)**2

RCS = 4*(3.1415)*(60)**4/3*(3**2)

RCS = 6,031,858 square centimeters

RCS = 603 square meters !!!!!

49. Maximum unambiguous range = c/(2*prf) = Ru

prf = c/(2*Ru) = 186,000 mi/sec / 300 mi = 620 pps

Minimum detection range = Delta R = c*tau/2 tau = 2*5 mi/186,000 mi/sec = 5.38*10**-5 sec

Duty cycle = Du = prf*tau = 620*(5.38*10**-5) = 0.0333

Average power = peak power * duty cycle

Average power = (10**6 watts)*(0.0333)= 33,300 watts

50. Lambda (wavelength) = c/f

f = (3*10**8)/(0.008) = 37.5*10**9 = 37.5 Gigahertz

CHAPTER VII

1. Define aircraft combat survivability.

2. How is a survivability assessment performed?

3. What are the commonly used measures of survivability?

4. What are the basic elements of a scenario?

5. Of the following, identify those items used to compute P<KSS>.

-Environmental conditions

-Probability threat is active

-Probability of detection

-Probability aircraft is within range of threat

-Ability of fire control/guidance system to direct the propagator against the aircraft

-Number of propagators launched/fired

-Fuzing employed (if any)

-Aircraft vulnerability

6. What are the variables of the P<K/D> function for proximity fuzed warheads?

7. What are the elements of the probability an aircraft survives an encounter with a single threat (P<S/E>)?

8. Two hostile encounters take place - one between an aircraft and a AAA battery, another between an aircraft and a SAM site. Determine which encounter the aircraft is more likely to survive, given the following encounter conditions.

ENCOUNTER A (AIRCRAFT VS SAM)

Cumulative probability of detection	0.72
Probability of launch/fire	0.50
Probability of kill given a single shot	0.88

The site can launch a total of four missiles.

ENCOUNTER B (AIRCRAFT VS AAA)

Cumulative probability of detection	0.61
Probability of launch/fire	1.00
Probability of kill given a single shot	0.003
Number of shots fired	820

9. What are the principal elements of the computation of sortie survivability?

10. Validate the approximation for sortie survivability by computing sortie survivability both ways for the following data:

M = number of encounters = 20

N = number of shots fired per encounter = 50

P<Di> = probability of detection for each encounter

P<Di> = 0.90

P<Li> = probability of launch for each encounter

P<Li> = 0.80

P<KSSi> = Probability of kill for a single shot for each encounter

P<KSSi> = 0.001

Is the approximaiton still valid if N = 4 and P<KSSi> = 0.7? What if N = 4 , M = 3, and P<KSSi> = 0.7?

11. List the computer programs currently accepted as standards by the JTCG/AS. Include the basic features of each.

12. Describe a campaign analysis. What items of information are necessary for input and what results are output?

13. What are effectiveness programs?

14. What is a survivability tradeoff study?

15. List the maintenance factors which might influence the potential inclusion of a survivability enhancement feature.

16. How can the inclusion of redundancy in a system decrease system reliability?

17. What is the single basis of comparison to which all survivability enhancement features must eventually be reduced? Why?

1. Aircraft combat survivability is the capability of an aircraft to avoid and/or withstand a man-made hostile environment.

2. A survivability assessment is done by combining:

   A. the results of the mission-threat analysis,

   B. the results of the vulnerability assessment, and

   C. the results of the susceptibility assessment.

3. The three most commonly used measures of survivability are:

   A. P<KSS>, the probability the aircraft is killed given a single shot.

   B. P<K/E>, The probability the aircraft is killed given a one-on-one encounter with a single weapon.

   C. P<K/M), the probability the aircraft is killed given multiple encounters or the sortie survivability.

4. A scenario is a description of the many parameters that characterize an encounter between an aircraft and a defensive weapon system. The parameters include the aircraft flight path, the

threat (type, number, location, and operations), the environmental conditions, and the terrain.

5. P<KSS> is computed using:

   A. Ability of the fire control/guidance system to direct the propagator against the aircraft

   B. Fuzing employed (if any)

   C. Aircraft vulnerability

6. The variables of the P<K/D> function are:

   A. Aircraft vulnerable area

   B. Location of the detonation

   C. The spray angle of the ejected fragments or propagators

   D. The number of fragments ejected

   E. The velocities of the varhead and aircraft

7. The elements of P<S/E> are:

   A. P<D> - cumulative probability of detection

   B. P<L> - probality of launch

   C. P<KSS> - probability of kill given a single shot

   D. N - the number of launches or firings

It should be noted that barage fire or a missile launched during a search does not require detection to take place.

8. ENCOUNTER A (AIRCRAFT VS SAM)

P<S/E> = (1.0 - (0.72) * (0.50) * (0.88)) **4

= (1.0 - 0.3168) **4

= (0.6832) **4

= 0.0101 = 1.01%

ENCOUNTER B (AIRCRAFT VS AAA)

P<S/E> = (1.0 - (0.61) * (1.0) * (0.003)) **820

= (1.0 - 0.0018) **820

= (.99817) **820

= 0.22269 = 22.27%

The aircraft is more likely to survive the encounter with the AAA site.

9. The principal elements of the computation of sortie survivability are:

A. The total number of aircraft in the raid

B. The number of weapons encountered

C. The probability of survival for each encounter

(It must be noted that multiple types of threats may be encountered and P<KSS> must be evaluated for each weapon system.)

10. The following BASIC program was run to evaluate the sortie survivability function.

```
10 PSS = 1
20 FOR M=1 to 20
30 FOR n=1 to 50
40 PSS = PSS*(1 - .9*.8*.001)
50 NEXT N
60 NEXT M
70 PRINT "PSS=";PSS
```

The result was: PSS= .486615

The approximation is:

P<S/S> ≐ exp((-1)(sum(m)P<K/E>)

= exp((-1)*50*20*0.9*0.8*0.001)

= exp(-0.72)

= 0.486752

The approximation is quite good for these conditions.

For the second set of input data

The exact result is: P<S/S> = 4.35E-25

The approximation is:

P<S/S> = exp(-(20*4*0.9*0.8*0.7))

= exp(-40.32) = 3.09E-18

Seven orders of magnitude difference.

However, it is so near zero that it makes little difference.

For the last set of input data,

The exact solution is: P<S/S> = 2.22E-4

The approximation is:

P<S/S> = exp(-(3*4*0.9*0.8*0.7))

= exp(-6.04)

= 2.36E-3

Still an order of magnitude error.

11. The currently accepted "standard" programs are:

A. BLUEMAX - Used to generate flight paths for fixed-wing subsonic aircraft, sea level to 20,000 feet. Used to simulate the ground attack scenario.

B. P001 - Used to evaluate an aircraft one-on-one engagement with a ground based gun system. Wide latitude is available in the gun characteristics. The program is capable of accepting maneuvering flight paths as input, but can only generate a straight and level flight path itself.

C. SAMS - Models the characteristics and capabilities of ten Soviet SAM systems (DOD desig. SA-2 through SA-11). MOdels sensor and tracking parameters, flight path dynamics and control, target vulnerability, and countermeasures. One-on-one engagements only. Warhead fuzing and detonation are also modeled.

D. PACAM V - Aerial combat is modeled in 3D. Asymetric tactics and the possibility of escape are allowed. Detection is a function of range and target size. Bomber penetration and defensive tactics are modeled, and ground launched SAMs may be used.

12. A campaign analysis is a mathematical modeling of multiple encounters between friendly aircraft and hostile air defense systems for a specified number of raids or sorties. Strike aircraft encounter multiple AAA, SAM, and AI in a zone defense pattern. Point defense weapons may be used in the vacinity of the target. The results can include the probability an aircraft survives the sortie, the probability an aircraft is damaged, and the number of bombs dropped on the target. Multiple raids on the target may be run by aircraft undamaged on previous raids.

13. Effectiveness programs (examples: TACOS and EVADE) are large scale computer programs which model large deployments of air defence systems attacked by many aircraft and missiles. Typically the terrain of the battle area is an input (or resident in the program) and terrain masking is allowed. Electronic countermeasures may be used, and command control of the air defence system may be used. Effectiveness programs produce prodigous ammounts of cross referenced data, and use significant ammounts of computer time.

14. If a survivability enhancement feature does not add cost, complexity, weight, performance, or some other type of penelty, it probably should be included in the design. Most enhancement features do involve penelties, however, and their inclusion in the design must be questioned. The survivability tradeoff study is a methodical study of the benefits and the penelties of each survivability enhancement feature, and must include cost, maintainability, performance, weight, reliability, logistics, and any other factors which can be quantified compared to the benefits to determine its validity and its desirability for inclusion on the aircraft.

15. A. Mean task times (or accessability)

B. Downtime per flight hour

C. Maintenance man hours per flight hour

16. If each duplicate component in a redundant system has the same reliability as the equivalent component in a single system, it could be expected that a failure of the system with duplicated components would occur twice as often. This could reduce system effectiveness and result in additional maintenance time to support the system.

17. Cost is the single basis for comparison of survivability enhancement features. It is a single measure by which all survivability enhancement features can be compared, and is in many cases the driving consideration for inclusion or exclusion of these features.

APPENDIX B

LEXICON OF SURVIVABILITY TERMS

For terms not listed below, please consult the index or MIL-STD-2089.

accumulator, hydraulic: A pressurised hydraulic reservoir which stores energy that can be returned to the system should the pump fail.

ACS - see aircraft combat survivability

actuator, hydraulic - see servoactuator

afterburner: Device attached to the tailpipe of a jet engine which injects additional fuel into the exhaust, where it burns to provide additional thrust.

aircraft combat survivability: The capability of an aircraft to avoid and/or withstand a man-made hostile environment.

AMSSA - U.S. Army Material Systems Analysis Activity

anhedral: Negative dihedral. When viewed from the back or front, a downward slope of the wing from the root to the tip.

anti-radiation missile: A missile which homes on radio transmissions, such as those of a radar.

API - armor piercing incendiary

atmospheric absorption: The decrease in the intensity of an electromagnetic signal due to interaction of the signal with molecules in the air, principally carbon dioxide and water in the case of infrared radiation.

autorotation: Unpowered descending state of flight in a helicopter, in which the rotor develops lift due to the flow of air past the blades as the helicopter descends.

AVSCOM - U.S. Army Aviation Systems Command

ballistic: Unguided flight, as of a projectile or a non-guided missile.

box beam: A rectangular load carrying member which has relatively thin sides and a relatively large open center. The sides parallel to the normal forces carry loads in shear, and the sides perpendicular to the normal force carry loads in tension and compression. Box beams are also used to carry torsional or twisting loads.

canard: A horizontal control surface on an airplane located forward of the wing.

CAS - see control augmentation system

chaff: Radar reflecting material, usually ejected from an aircraft to degrade search or fire control radars.

chromaticity: The tint or hue of an object; its color.

CNM - Chief of Naval Material

collective stick: A helicopter control lever which controls the net ammount of lift produced by the rotor system.

combat radius: The distance to which an aircraft can fly, perform its mission, and return to base with an adequate fuel reserve.

conditional probability: The probability that an event will occur, given the fact that another (possibly related) event has occurred.

contrail: A white trail of condensed water vapor that sometimes forms in the wake of an aircraft.

control augmentation system (CAS): An active control system in which both aircraft states and pilot control inputs are used as feedback signals to augment both his control and the stability of the aircraft.

control surface: A moveable panel hinged to a portion of the wing, fuselage, or empenage which when moved changes the airflow over the local surface.

countermeasure: The employment of devices and/or techniques with the objective of impairing the operational effectiveness of enemy activity.

CPA - closest point of approach

cruise speed: The normal operating speed of an aircraft in transit from one geographic position to another.

cyclic stick: A helicopter control lever which controls the direction of the lift vector of the rotor system.

damage mechanism: A warhead fragment, or any physical entity that can cause damage to an aircraft, such as an incindiary particle, a shock wave or a laser beam.

DARCOM - U.S. Army Material Development and Readiness Command

dash speed: A speed, higher than cruise speed, that is used on the final penetration to the target.

DCGMD - Deputy Commanding General for Material Development

deceiver: An electronic device used to spoof or fool a tracker by induceing errors in range and/or bearing, or by creating additional (spurious) targets.

deflagration wave: A relatively slow, low pressure combustion process which may or may not result in a sustained fire.

delayed failure: A design technique which attempts to lengthen the time between the occurance of damage of a component and the components failure.

detonation wave: A rapid combustion charactorized by a sudden rise in pressure.

dihedral: An upward slope of the centerline of the wings when viewed from the front or rear.

DOD - Department of Defense

drone - see remotely piloted vehicle

drop tank: A fuel tank carried outside of an aircraft, suspended from the wing or fuselage.

DSARC - Defense System Acquisition Review Council

ECM - electronic countermeasures

ECP - Engineering Change Proposal

EEA - see Essential Elements of Analysis

expendable: A relatively inexpensive device such as chaff, IR flares, etc. ejected by aircraft to decrease susceptibility.

FAC - Forward Air Controller

fail-safe response: A failure mode in which the failure of a component does not lead to additional system failure or damage.

fire-and-forget: Ordnance which requires no additional targeting information after launch.

flak: Slang term for anti-aircraft gunfire, particularly that which has a high explosive warhead.

FLIR - see forward looking infrared detector forward looking infrared detector: An Infrared imageing device which converts infrared data to video for cockpit display.

fly-by-wire: A Flight control system which uses electronic signals to provide the input signal to the actuator to position the flight controls, eliminating some or all of the mechanical pushrods and cables.

fod - see foreign object damage

Also, particles which can cause foreign object damage.

Foreign Object Damage: Damage to the rotating components of engines or rotor systems due to the ingestion of relatively small particles such as rivets, gravel, etc. Often causes catastrophic failure in turbine engines.

FSD - Full Scale Development

Gaussian distribution: A specific probability distribution that is symmetric about the mean and decreases above and below the mean.

glint: The rapid change in radar cross section for small changes in aircraft attitude.

GOR - General Operational Requirement

HE - high explosive

hydraulic ram: A large fluid pressure due to the penetration of a fluid containing vessel such as a fuel tank, by a high velocity penetrator.

hydrodynamic ram: see hydraulic ram

interceptor: An aircraft designed to rapidly take off and fly out to engage approaching enemy aircraft.

IR - infrared radiation

IR flare: A high intensity pyrotechnic device ejected from an aircraft in an attempt to decoy IR missiles and/or tracking devices.

jammer: A transmitting device which attempts to degrade or render useless tracking and/or fire control equipment.

JTCG/AS-Joint Technical Coordinating Group on Aircraft Survivability

JTCG/ME-Joint Technical Coordinating Group on Munitions Effectiveness

laser: Light Amplification by Stimulated Emission of Radiation. A source of monochromatic, coherent electromagnetic radiation.

launch-and-leave: The use of guided ordnance which does not require the launching aircraft to remain in the vicinity of the target following launch.

loiter time: The ammount of time an aircraft can delay while airborne (such as for weather) and still complete its assigned mission.

luminance: The luminous intensity of an object. Its brightness.

MAM - Mission Attainment Measure

MEWS - Mission Essential Weapon Systems

MOMS - Measure of Mission Success

NASP - Naval Air Survivability Program

NCG - Air Force Nuclear Criteria Group

NMC - Naval Material Command

OR - Operational Requirement

OSD - Office of the Secretary of Defense

PDF - Probability density function

PE - Probable error

PMD - Program Management Directive

propagator: Any projectile, missile, or radiation beam directed against an aircraft.

RCS: radar cross section

reheat - see afterburner

relaxed static stability: A design philosophy or technique which relies on a flight control computer to provide good flying qualities, rather than building the flying qualities into the aircraft. The aircraft may be unflyable if the flight control computer fails.

remotely piloted vehicle: An unmanned flight vehicle, controlled by radio signals or onboard systems. Sometimes used as decoys or for surveilance in areas considered too dangerous to fly manned aircraft.

retrofit: A change in the design of an existing aircraft to incorporate improvements.

RFP - request for proposal

RMS - root-mean-square

ROC - required operational capability

RPV - see remotely piloted vehicle

SAS - see stability augmentation system

servoactuator: A power device which uses mechanincal or electrical inputs to control its output. Used to position flight control surfaces.

speed brake: A control surface used primarily to increase aircraft drag. It is used to slow the aircraft rapidly and to increase the rate of descent without increasing aircraft speed.

spoiler: A control surface mounted on wings and used to decrease lift.

stability augmentation system (SAS):

An active control system in which certain aircraft states are sensed and used as feedback signals to augment the natural stability of an aircraft.

supercharger: A Mechanical device which compresses inlet combustion air to increase the power output of a reciporcating engine.

swashplate: The mechanical coupling device between the stationary servoactuators and the rotating rotor head of a helicopter which transmits control motion to the rotor head.

torque box: A hollow square or rectangular closed structure used to resist twisting.

TRAC - Threat Review Advisory Committee

TWS - track while scan

ullage: The open space above the fuel in a fuel tank.

UV - ultraviolet radiation

VUDEW: vulnerability to directed energy weapons

APPENDIX C

SURVIVABILITY TEXTBOOK INDEX

APPENDIX D

VARIABLES FOR EQUATIONS OF PROBABILITY

A<p>	Presented area of the aircraft
A<pi>	Presented area of the ith component
A<po>	Component overlap area
A<v>	Vulnerable area of the aircraft
A<vi>	Vulnerable area of the ith component
A<vo>	Vulnerable area of the overlap area
K<nrc>(j)	Probability one or more nonredundant components are killed after j hits
K<rc>(j)	Probability that all redundant components in a system are killed after j hits
P<CD>	Cumulative probability of detection
P<hi>	Probability of hit of the ith component
P<K>	Probability of aircraft kill
P<K>(j)	Probability the aircraft is killed after j hits
P<KSS>	Probability of aircraft kill given a single shot
P<ki>	Probability of kill of the ith component

P<K/E>	Probability of aircraft kill given a one-on-one encounter
P<K/H>	probability of aircraft kill, given a hit on the aircraft
P<ki>	Probability of kill of the ith component
P<k/hi>	Probability of kill given a hit of the ith component
P<k/ho>	Probability of kill of the overlap area
P<k/Hi>(j)	Probability of kill of the ith component due to the jth random hit on the aircraft
P<K/Hi>(j)	Probability of kill of the aircraft due to the jth hit on the aircraft
P<L>	Probability that a propagator will be launched/fired at the aircraft
P<S>	Probability of aircraft survival
P<S/E>	Probability the aircraft survives a single shot encounter
P<S/S>	Probability an aircraft survives a sortie
P<si>(j)	Probability the ith component will survive the jth random hit on on the aircraft
P<si>	Probability of survival of the ith component
P<si>(j)	Probability the ith component survives after n random hits on the aircraft

$P_{S}^{(n)}$	Probability of survival of the aircraft after n random hits on the aircraft
P_{So}	Probability of aircraft survival, given a hit in the overlap area
(T)	Kill transition matrix
$(S)^{(j)}$	Vector of probabilities that the aircraft exists in each of the possible states after the jth hit

GENERAL EQUATIONS OF PROBABILITY

Vulnerable area of the ith component

$$A<vi> = A<pi>*P<k/hi>$$

Probability of survival

$$P<S> = 1 - P<K>$$

Probability of kill of the ith component

$$P<k/Hi> = P<hi>*P<k/hi>$$

Probability of kill, given a hit of the ith component

$$P<k/hi> = A<vi>/A<pi>$$

Probability of hit of the ith component

$$P<hi> = A<pi>/A<p>$$

Probability of kill of the ith component.
given a random hit on the aircraft

$$P<k/Hi> = A<vi>/A<P>$$

SINGLE HIT VULNERABILITY, NO REDUNDANCY, NO OVERLAP

Probability of aircraft kill, given a hit on the aircraft

$$P<K/H> = \sum P<k/Hi>$$

$$P<K/H> = 1/A<P> * \sum A<vi>$$

$$P<K/H> = A<V>/A<P>$$

Vulnerable area of the aircraft

$$A<V> = \sum A<vi>$$

The above are valid for single hit calculations on a redundant aircraft with no overlap, with the observation that redundant components do not contribute to vulnerable area.

SINGLE HIT VULNERABILITY, NO REDUNDANCY, WITH OVERLAP

Probability of aircraft survival, given a hit of the overlap region

$$P\langle So\rangle = \prod P\langle si\rangle$$

$$P\langle So\rangle = \prod (1-P\langle k/hi\rangle)$$

Vulnerable area of the overlap area

$$A\langle vo\rangle = P\langle k/ho\rangle * A\langle po\rangle$$

SINGLE HIT VULNERABILITY, WITH REDUNDANCY, WITH OVERLAP

Probability of aircraft survival, given a hit on the overlap area

$$P<So> = P<S1>*P<S2>*P(1-P<k/h3>*P<k/h4>)*\ldots$$

Where $P(k/h3)$ and $P(k/h4)$ are the probabilities of kill given a hit on the third and fourth components.

MULTIPLE HIT VULNERABILITY, NO REDUNDANCY

Probability the ith component survives n random hits on the aircraft

$$P_{Si}^{(n)} = \prod P_{si}^{(j)}$$

$$P_{Si}^{(n)} = \prod \left(1 - P_{k/Hi}^{(j)}\right)$$

Probability the ith component survives the jth random hit on the aircraft

$$P_{si}^{(j)} = 1 - P_{k/Hi}^{(j)}$$

Probability of survival of the aircraft after n random hits

$$P_{S}^{(n)} = \prod \left(1 - P_{k/H}^{(j)}\right)$$

MULTIPLE HIT VULNERABILITY, WITH REDUNDANCY

Probability that the aircraft is in each of the possible states after the (j + 1)th hit

$$(S)^{(j+1)} = (T)(S)^{(j)}$$

Probability the aircraft is killed after the jth hit

$$P_{K}^{(j)} = K_{nrc}^{(j)} + K_{rc}^{(j)}$$

ENCOUNTER SURVIVABILITY

Probability the aircraft is killed in an
single shot encounter

P<K/E> = P<C/D>*P<L>*P<KSS>

Probability the aircraft survives the
single shot encounter

P<S/E> = 1 - P<K/E>

Probability the aircraft survives N gun shots
or missile launches

P<S/E> = (1-P<CD>*P<L>*P<KSS>)**N

If the probability of survival for each shot is nearly
unity, the following approximation may be used:

P<S/E> = exp(-N*P<CD>*P<L>*P<KSS>

The probability the aircraft survives M encounters of
N shots or launches each is

P<S/S> = (1-P<C D>*P<L>*P<KSS)**(M*N)

If the probabilities of survival of the individual
encounters is nearly unity, the following
approximation may be used:

P<S/S> = exp(-M*P<K/E>)

VARIABLES FOR EQUATIONS OF INFRARED RADIATION

A	Sensor area
cm	centimeter
L<a>	Atmospheric loss or attenuation of IR signature
P<I>	Aircraft IR signature in the direction of seeker (Watts/stearadian)
R<lo>	Lock on range of IR seeker
S<min>	Minimum power in the operating band required by the sensor for target lock-on
T	Degrees Kelvin
W	Radiant emittance
ϵ	Effective emissivity
λ	Wavelength
σ	Stefan-Boltzman constant $5.6697*10^{12}$ w/cm^2 K^4

GENERAL EQUATIONS OF INFRARED RADIATION

Gray body radiant emittance

$$W = \epsilon * \sigma * T^{4} \quad (\mathrm{Watts/cm^{2}})$$

Peak spectral emittance

$$= (3000) / T(\mathrm{K}) \quad (\mu \mathrm{m})$$

IR sensor lock on range

$$R_{lo} = (P_{I} * A / S_{min} * L_{a})^{0.5}$$

VARIABLES FOR EQUATIONS OF RADAR

A	Area of radar antenna
A<e>	Effective area of radar antenna
B	Bandwidth of radar receiver
C	Minimum J/S ratio that will conceal the echo in the noise
c	Velocity of propogation of electromagnetic radiation
F	Electric field strength at the receiving antenna
f	Frequency of electromagnetic waves
f<r>	Pulse repetition rate or frequency
f<d>	Doppler frequency
G<j>	Gain of jammer antenna in the direction of radar
G<r>	Gain of radar transmitting antenna
g	Vaires from 51 for a uniform illumination function to 80 for a cosine squared function
h<ac>	Height of aircraft in meters
h<ant>	Height of radar antenna in meters
J/S	Jammer to radar signal power ratio

L	Signal losses due to atmospheric attenuation and signal processing in the radar system
L<a>	Signal and echo loss due to atmospheric attenuation
L<s>	Radar system losses
N	Total noise in radar system
P<j>	Jammer power per unit bandwidth
P<r>	Peak power of radar transmitter
R	Distance from radar to aircraft
R<B>	Jammer burn through range
R<H>	Radar horizon in kilometers
R<max>	Maximum detection range of target
T	Noise factor per unit bandwidth ($4*10^{-22}$ Watts/Hz at room temperature)
V<r>	Radial velocity of the target
ξ<min>	Signal to noise ratio associated with a specific probability of detection and false alarm
λ	Wavelength of electromagnetic radiation
ρ	Antenna efficiency factor (0.6 is a nominal value)
σ	Radar cross section (RCS) of aircraft
τ	Pulse width

GENERAL EQUATIONS OF RADAR

Wavelength/frequency relationship

$$\lambda = c/f$$

Maximum unambiguous range

$$R_{u} = c/(2*f_{r})$$

Radar horizon

$$R_{H} = 6.5*((h_{ant})**0.5 + (h_{ac})**0.5)$$

Maximum detection range

$$R_{max} = (A/B)**0.25$$

where

$$A = (P_{r}*G_{r}^{2} * \lambda^{2} * \sigma * F^{4})$$

and

$$B = (4*\pi)^{3}*L_{s}*\xi_{min}*N*L_{a})$$

Range resolution

$$R = (c*)/2$$

Echo power received

$$S = P_{r}*G_{r}*A_{e}*\sigma/(4*\pi)^{2}*R^{4}$$

$$S = P_{r}*G_{r}^{2} *\lambda^{2} * \sigma/(4*\pi)^{3}*R^{4}$$

$$S = P_{r}*A_{e}^{2}*\sigma/4*\pi*\lambda^{2}*R^{4}$$

Echo power to noise ratio

$$S/N = P_{r}*G_{r}*\lambda^{2}*\sigma/(4*\pi)^{3}*R^{4}*L*N$$

$$S/N = P_{r}*G_{r}*\lambda^{2}*\sigma/(4*\pi)^{3}*R^{4}*L*T*B$$

Jam-to-signal ratio

$$J/S = (P_{j}*B*G_{j}/P_{r}*G_{r})*(4*\pi/\sigma)*R^{2}$$

Jammer burn through range

$$R_{B}=(P_{r}*G_{r}*\sigma*C/P_{j}*B*G_{j}*(4*\pi)**0.5$$

Average power/duty cycle relationship

$$P(\text{average}) = P_{r}*(\text{duty cycle})$$

Doppler frequency

$$f_{d} = 2*f*V_{r}/c = 2*V_{r}/\lambda$$

Antenna gain

$$G = 4*\pi*\rho*A/\lambda^{2}$$

$$G = 4*\pi*A_{e}/\lambda^{2}$$

Antenna beamwidth

$$BW = g*\lambda/D$$

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